

# Summary of the DICE model

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# Historical development

- Nordhaus WD. 1977. Strategies for the control of carbon dioxide. Cowles Foundation Discussion Paper.
- Nordhaus WD. 1977. Economic growth and climate: the carbon dioxide problem. *AER* 67(1):341-346.
- Nordhaus WD. 1991. To slow or not to slow: the economics of the greenhouse effect. *The Economics Journal* 101(407):920-937.
- Nordhaus WD. 1992. Optimal greenhouse gas reductions and tax policy in the “DICE” model. *AER* 83(2):313-317.
- Nordhaus WD. 1994. *Managing the Global Commons*. Cambridge, MA: MIT Press.
- Nordhaus WD, Yang Z. 1996. A regional dynamic general-equilibrium model of alternative climate-change strategies. *AER* 86(4):741-765.
- Nordhaus WD, Boyer J. 2000. *Warming the World*. Cambridge, MA: MIT Press.
- Nordhaus WD. 2008. *A Question of Balance*. Cambridge, MA: MIT Press.
- Nordhaus WD. 2010. Economic aspects of global warming in a post Copenhagen environment. *PNAS*.

# Applications

DICE is designed to:

- “...estimate the optimal path of capital accumulation and GHG – emissions reductions” (Nordhaus 1992, 1994).
- Compare taxes versus quantity controls under uncertainty, and investigate value of early information (Nordhaus 1994 Ch 8).
- Compare business as usual scenario and optimized policy to alternatives, e.g., Kyoto Protocol, similar to Stern Review, Gore emission reductions, temperature constraints (Nordhaus 2008).
- “Examine alternative outcomes for emissions, climate change, and damages under different policy scenarios” and calculate the near term carbon prices along alternative policy paths (Nordhaus 2010).

# Applications

DICE has been modified by others to examine a wide range of climate change economics issues, e.g.,

- Pizer (1999) [P vs Q for climate policy]
- Popp (2004) [endogenous technical change]
- Baker *et al.* (2006) [optimal R&D policy]
- Hoel and Sterner (2007) [relative prices of market vs non-market consumption]
- Yang (2008) [strategic bargaining in international negotiations]
- de Bruin *et al.* (2009) [optimal adaptation policy]

# One-slide summary

- **Dynamic Integrated Climate-Economy model**
- Optimal economic growth model + a simplified climate change model + a damage function that represents the loss of economic output due to increased global surface temperatures + projection of abatement costs over time.
- Solves for optimal path of savings and abatement to maximize present value of discounted aggregate utility.
- Some key results from DICE2007 (Nordhaus 2008):
  - $SCC_{2005}$  in baseline scenario  $\approx \$7.5/\text{tCO}_2$  ( $\approx$  optimal carbon tax)
  - $SCC$  growth rate  $\approx 0.02/\text{yr}$
  - Max temp increase  $\approx 6^\circ\text{C}$  (no controls for 250 yrs);  $\approx 3.5^\circ\text{C}$  (optimal)
- New results from RICE2010 in Nordhaus (2010) *PNAS*

# Model structure

- Net output = gross output from economic production
  - fraction of output lost due to climate damages
  - fraction of output spent on abatement
- Consumption = net output – savings
- Capital accumulation = savings – depreciation
- Temperature = “three-box” climate model calibrated to MAGGIC
- Choose savings and abatement to max present value of future utilities, where utility depends on per-capita consumption in each period
- Key quantities:
  - Pure rate of time preference = 0.015/yr
  - Elasticity of m.u. of consumption = -2
  - Initial per capita consumption growth rate  $\approx 0.016/\text{yr}$
  - Damages at 3 deg C  $\approx 2.5\%$  of world GDP
  - Damages at 6 deg C  $\approx 9.3\%$  of world GDP

# The SCC in DICE

Social cost of carbon = shadow value of emissions ÷  
shadow value of capital stock

Along an optimal path this will equal:

1. the change in consumption in all future years from one additional unit of emissions in the current year, discounted to present value using the Ramsey consumption discount rate, and
2. the tax on CO<sub>2</sub> emissions.



# Calibration of damage function

Basic strategy:

1. Choose a functional form for aggregate climate change damages as a fraction of global economic output (e.g., low order polynomial).
2. Calibrate damage function parameters using summary of empirical studies of climate change damages in all major categories, extrapolating among regions as necessary:
  - agriculture, sea-level rise, other market sectors, health, nonmarket amenity impacts, human settlements and ecosystems, catastrophes.

(Nordhaus & Boyer 2000)

# Sector by sector

## Example 1 – Agriculture:

- Similar calibration strategy for some other sectors
- Draw on estimates from previous studies of the potential economic losses in each category at a benchmark level of warming of 2.5°C
- Extrapolate across regions as necessary to cover data gaps using income elasticities for each impact category
- “United States agriculture can serve here as an example. Our estimate is that [the fraction of the value of agricultural output lost at 2.5°C] is 0.065 percent [based on Darwin *et al.* 1995]... The income elasticity of the impact index is estimated to be - 0.1, based on the declining share of agriculture in output as per capita output rises” (Nordhaus and Boyer 2000 p 74-75).

# Sector by sector

## Example 2 – Health:

- Based on effects of pollution and a broad group of climate-related tropical diseases including malaria and dengue fever
- Changes in mortality from more severe summers and less severe winters were assumed to roughly offset and so were not included
- Using data from Murray and Lopez (1996), regress the log of climate related YLLs [years of life lost] on mean regional temperature
- Plus judgmental adjustments “to approximate the difference among subregions that is climate related”
- Each YLL valued at two years of per capita income (Nordhaus and Boyer 2000 p 80-82).

# Sector by sector

## Example 3 – Catastrophes:

- Based on results from survey of climate experts (Nordhaus 1994). Experts asked for likelihood of a catastrophe (i.e., 25% loss of global income indefinitely) if the global average temp increased by 3°C and by 6°C within 100 years.
- Average responses adjusted upward based on “heightened concerns about the risks associated with major geophysical changes...”
- Probability of 30% loss of global income assumed to be 1.2% with 2.5°C and 6.8% with 6°C of warming. CRRA = 4 used to calculate WTP to avoid catastrophic risks.
- WTPs between 0.45% and 1.9% of income for 2.5°C and between 2.5% and 10.8% for 6°C warming. Assumed that this WTP has income elasticity = 0.1

# Sector by sector

Category	Damages at 2.5°C [ % of global output ]	
	Output weighted	Population weighted
Agriculture	0.13	0.17
Sea-level rise	0.32	0.12
Other market sectors	0.05	0.23
Health	0.10	0.56
Non-market amenities	-0.29	-0.03
Human settlements & ecosystems	0.17	0.10
Catastrophes	1.02	1.05
<b>Total</b>	<b>1.50</b>	<b>1.88</b>

(Nordhaus & Boyer 2000)

# Aggregation of damages

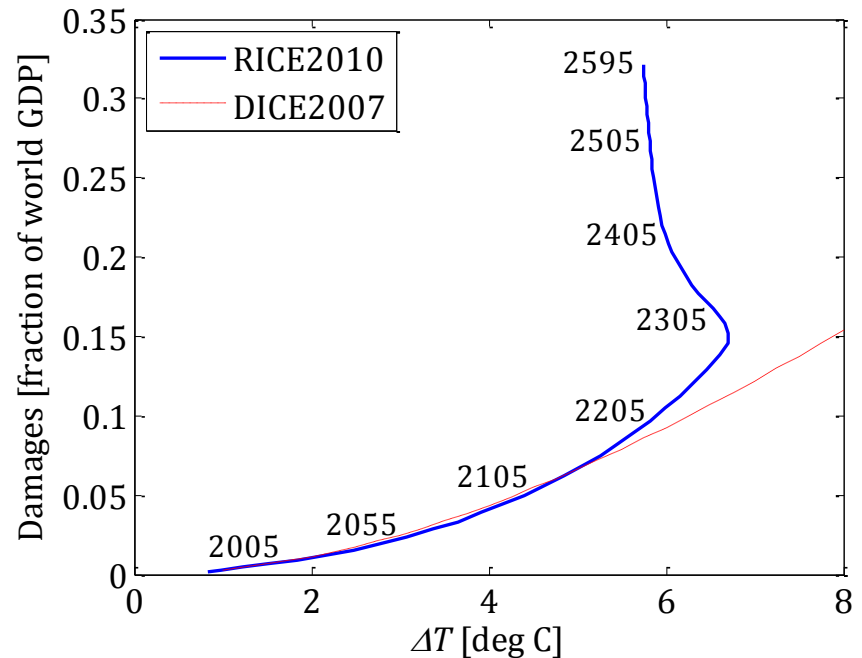
RICE/DICE1999 (Nordhaus & Boyer 2000):

1. Calculate regional impacts for 2.5°C and 6°C.
2. Sum across categories to create overall impacts for each region.
3. Solve system of 2 quadratic equations for each region to obtain quadratic damage function parameters for each region.
4. DICE quadratic damage function calibrated “so that the optimal carbon tax and emissions control rates in DICE-99 matched the projections of these variables in the optimal run of RICE-99.”

# Update: RICE2010

Nordhaus (2010):

- Parameters: pure rate of time preference = 0.015/yr, elasticity of m.u. of consumption = -1.5, initial growth rate of per cap consumption  $\approx$  0.022/yr.
- “...provides a revised set of damage estimates based on a recent review of the literature [Tol 2009, IPCC 2007]. Damages are a function of temperature, SLR, and CO<sub>2</sub> concentrations and are region-specific.”
- Near term carbon price on optimal path  $\approx$  \$11/ton CO<sub>2</sub>



RICE2010 damages plotted against temperature change relative to pre-industrial in each year.